

## **Plankton Production Biology**

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### **LONG-TERM GOALS**

I continue to investigate geographic and seasonal distributions of hydrographic, chemical, and planktological phenomena in the central and eastern Arabian Sea, now emphasizing the continental shelf off the Indian west coast and Pakistan. Occasionally I will comment on general oceanographic or ecological principles.

### **OBJECTIVES**

To study old and new oceanographic issues about the central and eastern Arabian Sea including the Indian shelf, often together with colleagues at India's National Institute of Oceanography in Dona Paula (Goa; NIO) or the headquarters of the Central Marine Fisheries Research Institute in Cochin (Kerala; CMFRI), and mostly by mining old data.

### **APPROACH**

Largely we (KB and scientists at NIO and CMFRI) use existing data, some of which are not yet in data centers. I enjoy the trust of Indian colleagues, so observations from inside the Indian Exclusive Economic Zone are available. As always, the accuracy of the measurements is of concern, as of course is true also with U.S. sources. T-S relations are being used for checking, but for O<sub>2</sub> new twists have developed (see RESULTS [1]).

### **WORK COMPLETED**

Work in progress was reported in February 2010 at the Ocean Sciences Meeting in Portland, OR, and in July at the annual workshop of NSF's Ocean Carbon and Biogeochemistry group in La Jolla, CA. In Portland a lecture presented "Do the open-ocean Oxygen Minimum Zones intensify and expand?" (OS-10, Bo21 B02); and a poster addressed "Is the recent recurrent anoxia of the southwest monsoon along much of India's west coast to last?" (OS-10, IT35 K-01). In La Jolla, posters were shown on the second subject but further developed, as well as one entitled "Twists in estimating time changes of dissolved O<sub>2</sub> in oxygen minimum zones from old O<sub>2</sub> data" (see RESULTS below).

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## RESULTS

As a spin-off from our ongoing study of the temporal stability of the Oxygen Minimum Zone of the Arabian Sea we have discovered the role of a switch during the 1970s to 1980s in the method for endpoint detection for the Winkler analysis of dissolved oxygen, which remains the standard oceanographic and limnological field method (**1., below**). We also address the cause(s) of the recent recurrent sulfidic anoxia of the southwest (summer) monsoon on the inner shelf of the central west coast of India with its drastic effect on the fisheries of bottom fish and prawns (**2., below**). Because of the timeliness of the subjects, I decided to prepare the papers and postponed following the plans laid out by the proposal for FY 2010. During FY 2011, I will return to the tasks without new ONR funding.

**1. Twists in estimating temporal O<sub>2</sub> changes in oxygen minimum zones from old O<sub>2</sub> data. A manuscript is being prepared for submission to Geophysical Research Letters** (K. Banse<sup>1</sup>, S. W. A. Naqvi<sup>2</sup>, J. R. Postel<sup>1</sup> and P. V. Narvekar<sup>2</sup>).

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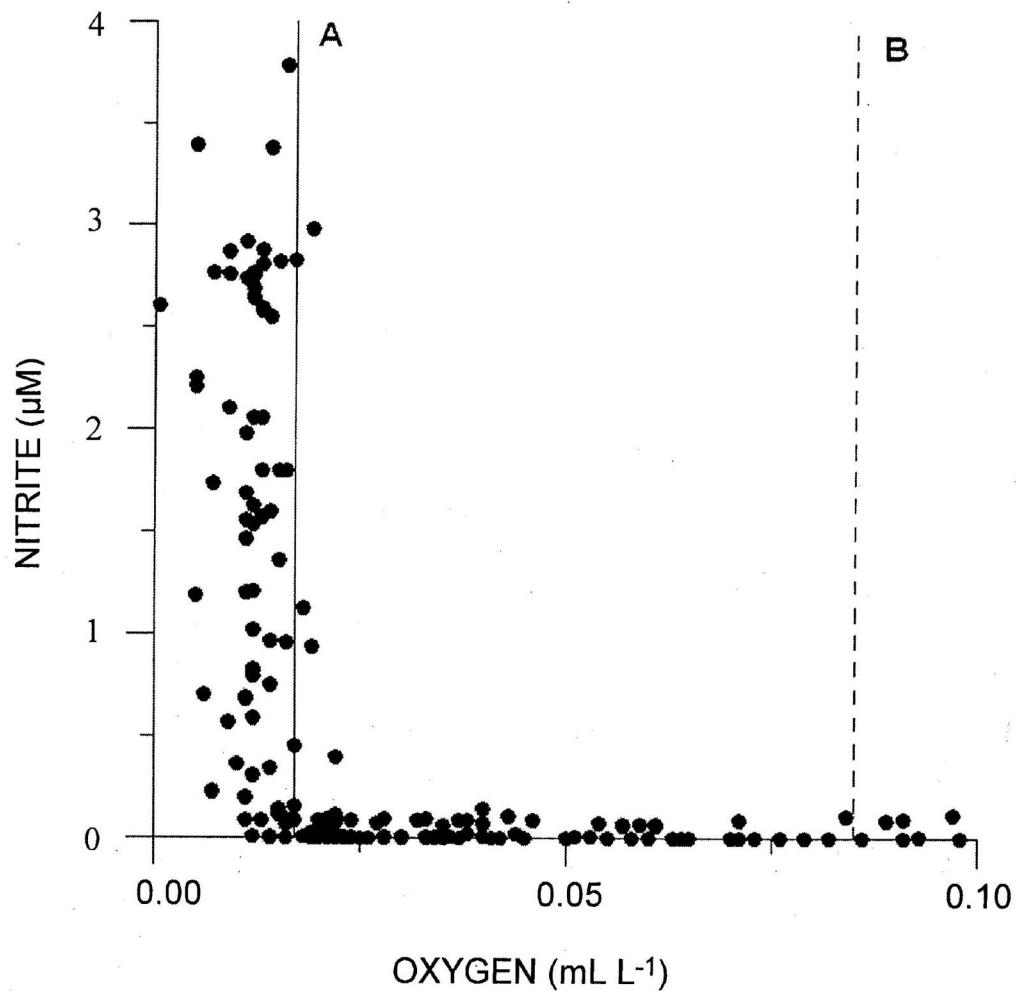
<sup>2</sup> National Institute of Oceanography, Dona Paula, Goa, 403 004, India

We suggest a source of bias in time series on which the answers to questions of temporal change of oxygen in the oceans must rest. During about the last two decades the issue of whether the open-ocean oxygen minimum zones (OMZs) intensify and expand has attracted more and more interest (e.g., Stramma et al., 2008). The three largest OMZs exist in the eastern tropical North and South Pacific and the Arabian Sea. The latter is the biggest one and extends between 150 and 1,000 m depth where O<sub>2</sub> is  $\leq 0.1 \text{ mL L}^{-1}$  ( $\sim 4 \mu\text{M}$ ) over about 10° of latitude. The geochemical significance of OMZs is the reduction of nitrate from the perpetual lightning over the sea, runoff, and N<sub>2</sub> fixation, by the liberation of dinitrogen (N<sub>2</sub>) below about 0.02 mL L<sup>-1</sup>, or  $\sim 0.75 \mu\text{M O}_2$ . The oceans' nitrogen balance is maintained (or so we assume), and as a by-product, the greenhouse gas N<sub>2</sub>O is generated. *Does climate change affect the intensity and geographic extent of the OMZ(s)?*

Time series of O<sub>2</sub> in OMZs regarded as accurate enough to establish change, if any, extend back to about 1960. The O<sub>2</sub> content continues to be measured by the Winkler titration method. The endpoint, however, used to be determined visually (VED). We find that the change to automated (e.g., potentiometric) endpoint detection (AED), two or three decades ago, has affected the results at the very low concentrations of the OMZs. The new measurements are significantly lower than the old observations, the difference ranging between  $\sim 0.05$  and  $0.10 \text{ mL L}^{-1}$  O<sub>2</sub> (about 25-50  $\mu\text{M}$ ). For example, Figure 1 illustrates the median difference between 44 VED and 48 AED measurements at four depths in three large regions of the open eastern Arabian Sea during the same seasons of 1994-1995. The VED bias varies among operators and institutions and so, its size cannot be assessed *post-hoc*. Only a partial correction may be achieved because denitrification is restricted to very low O<sub>2</sub> concentrations (AED,  $\sim 0.02 \text{ mL L}^{-1}$ ,  $\sim 0.75 \mu\text{M}$ ). VED values  $\geq 0.1 \text{ mL L}^{-1}$  O<sub>2</sub> ( $\sim 50 \mu\text{M}$ ) accompanied by NO<sub>2</sub>  $\geq 0.2 \mu\text{M}$  are faulty and should be dropped. Much of the bias can be eliminated by the addition of azide to the pickling reagent.

*Oceanographic data centers, e.g., the U.S. NODC, have not yet recognized the systematic error (bias) in their O<sub>2</sub> data, but have only removed variability (outliers, duplicates, etc.) by statistical analysis. Therefore, when O<sub>2</sub> time series at very low O<sub>2</sub> concentrations are extended back to 1960, bias in the VED observations from the 1960s onward may falsely make a decadal decline of O<sub>2</sub> appear as real. The early values are not flagged, but a cutoff by the year of observation is not advisable because of the only gradual introduction of AED. So, as long as the data centers do not label questionable data,*

investigators looking into time series of  $O_2$  need to forego averages and interpolations, which are the basis for climatology or the World Ocean Atlases issued by NOAA, but must pursue the original data reports.



**Fig 1.**  $NO_2^-$  on  $O_2$  in the same samples from the eastern Arabian Sea. Line A indicates the denitrification threshold as > 90% of  $NO_2^-$  values exceeding  $0.2 \mu M$  occurred at colorimetric  $O_2$  values (AED, by the method of Broenkow and Cline, 1969) of  $\leq 0.02 \text{ mL L}^{-1} O_2$  ( $0.75 \mu M$ ). The example for a VED threshold (line B) is the median difference between 44 VED and 48 AED measurements at four depths in the same region during the same seasons. Original.

The world's oceanographic data centers will have to annotate their sets of  $O_2$  measurements, at least in respect to the use of VED or AED and of azide. Because the methods may not be told in the institutional reports but rest only in the investigators' heads, some urgency is recommended.

**2. Is the recurrent recent sulfidic anoxia of the southwest monsoon on the inner shelf of India's west coast to last? A manuscript is being prepared for submission to Continental Shelf Research**  
(K. Banse<sup>1</sup>, S.W.A. Naqvi<sup>2</sup>, J.R. Postel<sup>1</sup>, and P.V. Narvekar<sup>2</sup>).

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Upwelling off southern Sri Lanka and southwest India during the southwest (summer) monsoon (SWM) was noticed from monthly climatological maps of sea surface temperature by Schott (1935, Table 23; copied by Sverdrup et al., 1942: Chart 3). For decades it did not receive attention and even now, it is little known outside of India. During the SWM season, cool water from the upper and mid-thermocline is upsloping for many months all along India's and Pakistan's Arabian Sea shores and is upwelling off the southwest coast of India (e.g., Banse, 1968). The hydrography then is similar to that of a typical eastern boundary current except that there is heavy rain and runoff. Also, the upwelling is initiated not by local winds but by Kelvin waves originating in the Bay of Bengal and traveling around Sri Lanka (McCreary et al., 1993; Shankar and Shetye, 1997).

In consequence, water low in dissolved O<sub>2</sub> covers most of the shelf from May/June until November/early December across ~12° of latitude up to the 10-20 m isobaths and enters also the deeper estuaries near the bottom. The phytoplankton blooms engendered by the upwelled nutrients lead to large secondary production and pelagic fisheries yields, but sinking organic material reduces the sub-thermocline O<sub>2</sub> over much of the shelf to  $\leq 0.1 \text{ mL}^{-1}$  ( $\sim 4 \mu\text{M}$ ). *Since the SWM seasons of the mid-1990s and perhaps the mid-1980's, however, sub-thermocline sulfidic anoxia is occurring for about two months inshore along the central west coast of India with drastic effects on the fishery of demersal fish and prawns.* Eutrophication from greatly enhanced use of fertilizers in India and enhanced atmospheric deposition was tentatively suggested as the cause (Naqvi et al., 2000, 2009).

Nitrogen is the limiting nutrient for phytoplankton in the region. Our review of scant time series for the two major estuaries south of Mumbai (the Mandoviv-Zuari in Goa and the Kerala backwaters near Kochi) suggests that during the past two-three decades the rivers have not exported more NO<sub>3</sub><sup>-</sup> than before. Further, from estimates of the freshwater inventory we figure that even a doubling or more of the present nutrient loading at the river mouths (adding New Production to the surface layer) would not suffice to remove the NO<sub>3</sub><sup>-</sup> inventory in the sub-pycnocline water column, which is the prerequisite for SO<sub>4</sub><sup>2-</sup> reduction. Instead, without actual data, *we postulate a climate-caused hydrographic change, e.g., slightly lowered initial O<sub>2</sub> in the advected source water or a slightly increased residence time once on the shelf.* For the latter scenario, the O<sub>2</sub> remaining would vanish in days, while the removal of nitrate is likely to take several weeks. The H<sub>2</sub>S is first observed inshore rather than mid-shelf because of the smaller NO<sub>3</sub><sup>-</sup> inventory in shallow water.

We expect that the climate may at some time return to the earlier state and provide better ventilation below the pycnocline and so, relieve the plight of the fishery. Such climatic regime shifts are more and more often observed since long time series have become established (e.g., Karl et al., 2001; Bakun, 2004). *Our hypothesis about the cause of the recent sulfidic anoxia is in principle testable, although in practice it will be difficult to pursue because of the scarcity and type of data.*

**3. The stable southern border zone of the OMZ in the central Arabian Sea.** The preparation of a paper (see Annual Report for FY 2009, item 2) was delayed because papers 1 and 2 (above) seemed more important. We had found that in the central Arabian Sea at least during the mid-1980s to the mid-1990s *the position of the southern border zone of the OMZ between 150 and  $\geq 500 \text{ m}$  depth was*

*stable within about 2-3° of latitude and correlated with hydrographic change.* We infer that the location of the border is determined by hydrography rather than a shifted balance between supply and consumption of O<sub>2</sub>.

**4. Translations of monographs from the Russian.** *Scientists in the “West” are largely ignorant about the Soviet and Russian oceanographic publications unless they appear in the few journals translated from cover to cover, and sometimes try to re-invent the wheel.* Therefore in my earlier grants, the ONR had supported translations of five monographs and the commission of a new book in English about the last integrated Ukrainian expedition to the northern Arabian Sea in 1990. The financial and logistic problems of editing and printing the manuscripts has led to long delays and in part continues to do so, so that only three books have seen the light (Pavlova, 2006; Sazhina, 2006; Banse and Piontkovski, 2006).

*Rough translations of three more manuscripts are in hand, two by Petipa (1986, 1993) and one by Sazhina (1985).* The former two treat “comprehensive” expeditions (i.e., integrated from hydrography to zooplankton, with species counts and biomass estimates, mostly for the upper 150-200 m) to two essentially wind-generated divergences in the equatorial Indian Ocean, with nets of stations usually 55 km apart. During the NE (winter) monsoons of 1984 and 1987, they visited twice the same sites of the Southern Sub-Equatorial Divergence at about 8°S, 65°E (also known as the Seychelles-Chagos Thermocline Ridge), which separates the upper 1-2 km of the Arabian Sea from the South Indian Ocean, as well as the north-equatorial counterpart near 3°N, 97°E. Both regions are under-studied. The book by Sazhina provides illustrated keys for all stages of the nauplii (copepod larvae) of 85 species common in the oceans and is the first and still the only one of its kind. Since biology proceeds through species rather than carbon and chlorophyll, the work once available, will be invaluable.

Because of the difficulty or near-impossibility of printing, which developed during the processing of the first three monographs, for years I did not edit the rough texts of the three works. The tables had been retyped and figures largely redrawn and are ready for printing. Now, as stated on p. 2 of my Planning Letter for FY 2011, the NIO in Goa is welcoming manuscripts of this kind and so far, has agreed to take care of the page layout, publication, and distribution of one monograph in electronic form. Last month, we were visited by Senior Lecturer Andrew G. Hirst of the University of London, Queen Mary, School of Biological and Chemical Sciences, who volunteered to do the editing and in the mean time has started to do so.

## **IMPACT/APPLICATIONS**

- 1.** The recognition of the bias in O<sub>2</sub> determination at the low level defining the Oxygen Minimum Zones (OMZs) should lead to the checking of conclusions about intensification and expansion of those sites or regions where time series dating back to the 1960s or 1970s exist. Such re-consideration may affect estimates of denitrification and of the oceans’ nitrogen budget.
- 2.** If our hypothesis about the cause of the recurrent sulfidic anoxia turns out to be correct, a major economic shift of the fisheries yield would result after the reversal of the hydrography to the earlier state, albeit without anyone doing anything. If the cause, however, were the great increase of fertilizer use (coastal eutrophication), nothing about the effects on fisheries and the marine environment at large needs to be done either, since grain production for India’s masses has to take precedence.

**3.** Sazhina's (1985) keys for copepod nauplii still are the only ones anywhere. They will permit the study of stage-specific population dynamics (growth rate, production, mortality) of copepod larvae in mixed populations.

## TRANSITIONS

The world's oceanographic data centers will have to annotate their sets of oxygen data (see the last paragraph of RESULTS, 1.), perhaps to be induced by the International Oceanographic Commission (IOC). Detailing the descriptions of methods for salinity and nutrients might also be of great value (see Dickson, 2010)

## RELATED PROJECTS

I continue to stay in contact with India's National Institute of Oceanography (NIO) in Goa and occasionally advise the director.

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